Intraoral laser welding

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1. Introduction

Just after the introduction of the first laser by Maiman, in 1960, there has been a very fast evolution of this new technology characterized by the constant progression about techniques and applications, devices ever more efficient, smaller and cheaper, and the introduction of ever-new wavelengths.
One interesting application of this new technology was the possibility to weld many kinds of metals and, in industrial fields, this procedure spread in a very short time.
Laser welding was firstly introduced in jewellery during years 70 and, just after, it was successfully used also by dental technicians (Maddox, 1970).
Initially, CO2 and Nd:YAG were used but, finally, the second one rapidly conquered the market due to the results obtained (Shinoda et al, 1991- Yamagishi et al, 1993)
Laser welding, in fact, gives a greater number of advantages than traditional welding.
First of all laser device saves time in commercial laboratory because welding is completely done directly on the master cast. Inaccuracies of assembly caused by transfers from the master cast along with investment are reduced. (Berg et al, 1995)
Then, the heat source is a concentrated and high power light beam able to minimize distortion problems on the prosthetic pieces. (Santos et al, 2003)
Another interesting aspect is the possibility to weld very close to acrylic resin or ceramic parts without physical (cracking) or colour damage (Bertrand et al, 1995)): this means to save time and money during the restoration of broken prosthetics or orthodontics appliances because of the possibility to avoid the remaking of the non-metallic portions.
This welding technique may be used on every kind of metal but the property to be very active on titanium makes it very interesting and specific for the prosthetics over endosseous implants. (Walter et al, 1999)
Many laboratory tests have demonstrated laser welding joints have a high reproducible strength for all metals, consistent with that of the substrate alloy. (Bertrand et al, 2004)
All these advantages gave to this procedure a great diffusion in the technician laboratories and stimulated the companies to put in the market more and more upgraded appliances.
Some aspects, such great dimensions, high costs and delivery system by fixed lenses today still characterize these machines, strictly limiting their use only to technician laboratories.
Moreover, the management of this appliance is very difficult, due to the number of the parameters involved and the factors related to the welding process. For these reasons, it

results strictly dependent by operator and influenced by the duration of the training period (Bertrand & Poulon-Quintin, 2009).
The first aim of this study was to value the possibility to utilize, for laser welding, the same device normally used in dental office. This gives the advantage to be used by dentist himself, being easier and with few parameters to adjust, and to avoid costs for the appliance, because it is the same of dental cares.
Moreover the dentist may avoid to send prosthetics to the lab and, sometimes, to take impressions, with patient receiving his repaired prosthetics after a very short waiting.
The second aim was to reach the result to weld directly into the mouth by means of the utilisation of a fibber-delivered laser after a careful valuation of the biologically compatibility of the procedure.
The advantages of this technique, defined Intraoral Laser Welding (ILW), consist in the possibility to fix the position of the different parts of the prosthetics without utilisation of acrylic resins and/or silicon impressions, and to repair damaged fixed prosthetics without their removal from the mouth.

2. Materials and Methods

The first step of our research was to determine what wavelength, among these normally utilised by dentist in his office and also in industrial field to make a real welding process (CO2 -10600 nm, Diode laser -810 nm and Nd:YAG -1064 nm.) was able for our work. Some tests have been realized with metallic plates showing that proper wavelength was the Nd:YAG laser.
In fact, in dental CO2 laser the pulse durations are too short (microseconds) and cannot give the thermal elevation necessary to obtain a fusion of metal while in Diode dental laser output power is too low (from 5 to 10 watt) and cannot give the Energy necessary to make a real welding process.
We decided so to use the appliance FIDELIS PLUS III (FOTONA, Slovenia) (Fig. 1) which is a combination of two different wavelengths, Er:YAG (λ=2940 nm) and Nd:YAG (λ=1064 nm).

Fig. 1. The utilized appliance Fidelis Plus III

The first allows to the dentist to treat hard tissues (enamel, dentin and bone) by a mechanism, which, utilizing the affinity of this laser with water and hydroxyapatite, induces the explosion of intracellular water molecules and so causes the ablation of the tissues. (Keller & Hibst, 1989)
Its utilisation may be extended also to the dermatology, where it can be employed, in addition to the elimination, by vaporizing them, of lesions such condyloma, naevi, warts, mollusca contagiosa, to the treatment of cheloid scars and wrinkles with the so-called "resurfacing". (Khatri, 2003)
Nd:YAG laser allows to the dentist to make surgery with complete emosthasis, thanks to the affinity of this wavelength with haemoglobin, and so to avoid the use of sutures. (White et al, 1992).
The delivery system, in this laser, consists of optical fibres of different sizes, chosen in conformity with the kind of application; the dimension go from 200 µm (endodontics) to 900 µm (bleaching).
The peculiarity of the appliance FIDELIS PLUS III is given by the possibility to have, in addition to pulse duration of microsecond which are necessary during dental interventions, even pulse durations of millisecond (15 or 25). This gives the possibility to use it also in flebology, in the treatment of inestethisms of vascular origin, thanks to the affinity of this wavelength for haemoglobin. (Scherer & Waner, 2007)
The optical fibre delivery system is a very important advantage of this device, by the point of view of the intraoral welding, because it is a very flexible and ergonomic, able to penetrate into the oral cavity.
We decided to use a fibre of 900 µm of diameter, normally used for bleaching and biostimulation.
Initially a handpiece with a 2 mm-spot (Fotona R 30), normally used in dermatology, was chosen and, by reducing the working distance, a spot of 1mm was obtained. Manufacturer took part in the first experimental step of our work by the realization of an handpiece able to generate a 0.6 mm spot. The aim was to increase the Fluence (J/cm2) which is the most important parameter determining the quantity of energy delivered to a surface, by a factor of 10, while also utilizing the device's maximum energy output (9.90J).

Fig. 2. The metallic support used in order to put firmly handpiece

Before each test we evaluated the output power with a powermeter (Ophir Nova II with thermal head F150A, Ophir, Jerusalem, Israel) in order to verify the stability of the laser's energy delivered.
A metal support, in which the handpiece was securely placed, was developed to maintain the correct working distance and to obtain a better management of the welding process (Fig.2).
To determine the proper parameters of the device, in order to obtain a real welding process causing the minimal thermal damage to the matter, several tests were performed.
A CrCoMo plate (25X50X10 mm) (Fig.3) was cast, sandblasted with alumina powder (50-mm), rinsed and degreased with acetone.

Fig. 3. The CrCoMo plate shot with different parameters.

Various combinations of welding parameters were tested on this alloy plate. The tests consisted of shooting the plate's surface with the laser: the spot's configuration was then analyzed using an interferometric technique. Interferometry is a non-contact optical technique for measuring surface height and shape with great speed and accuracy. Interferometry makes it possible to precisely measure, in three dimensions, shape and size of the laser's crater in the metal surface and allowed us to choose the laser parameters that well welded with minimal collateral damage to the surrounding area.
Interferometric analysis were performed by Prof. Caroline Bertrand at CNRS Laboratory of Bordeaux (France).
The following parameters were selected:
Output Power= 9.85 W, Frequency= 1 Hz, Pulse Duration= 150 msec, Working Distance 40 mm, Energy= 9.85 J, Fluence= 3300 J/cm2.
Best results were obtained by using the maximum power output and the minimum frequency of the device and at a pulse duration of 25 msec we noted cracks and fissurations (Fig 4) while, at a pulse duration of 15 msec, we did not observe these features (Fig. 5).

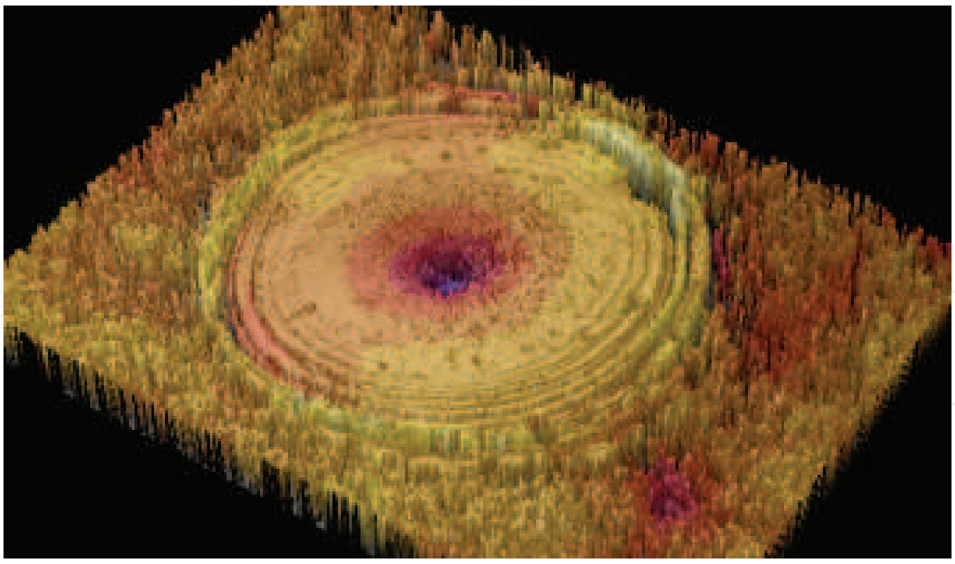

Fig. 4. 15 msec shot: no evidence of fissurations.

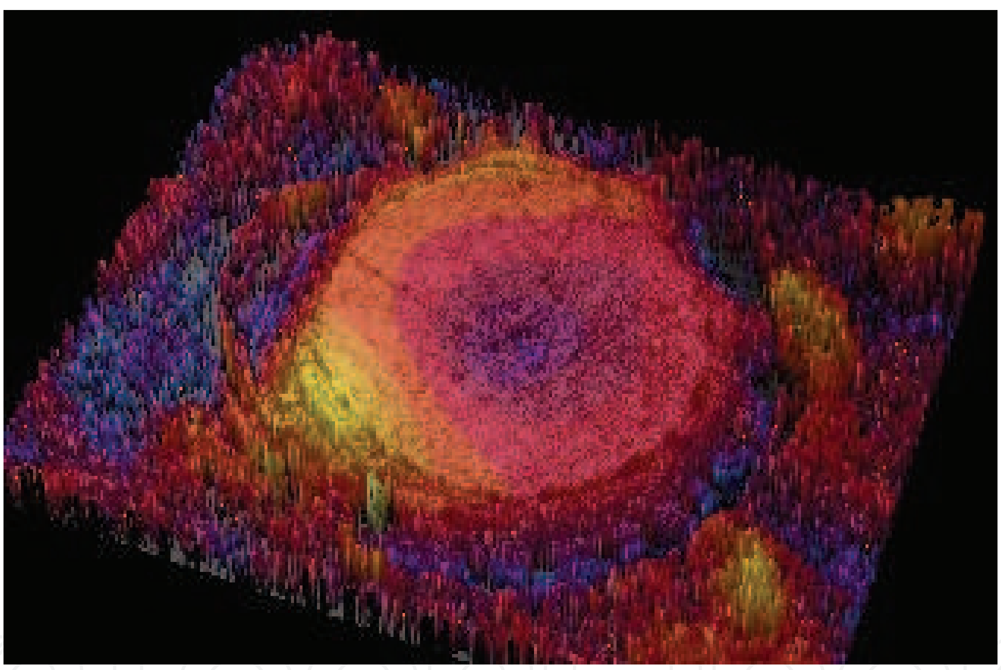

Fig. 5. 25 msec shot: presence of fissurations.

Other tests were then realized in order to compare the quality of welding process obtained with the office laser vs. that obtained by a technician laboratory welding laser.
We compared, by optical microscope, using laser beam over different Co-Cr-Mo plates, the welding process obtained by dental office Nd:YAG laser (Fidelis Plus III, Fotona), with the parameters previously described, and dental technician laboratory Nd:YAG laser (Rofin, Germany). This device was used with these parameters:
Volt 310, Energy/Pulse 3.0 J, 4.5 Hz Frequency, Pulse Duration
1.9 msec, Output Power 2.6 KW, Fluence 1516 J/cm2
We appreciated that they were very similar, except for the dimension of the welded bead, that was smaller in dental laser tested plates, due to the different spots used. (Figure 6)

Fig. 6. Comparison between office and laboratory laser welding beads

Then we made other tests to see ultrastructural aspects and strength of the laser welding joints.
Sixteen Argeloy NP Special® (Argen Corporation, Dusseldorf, Germany) (composition: 31.5%Cr, 5%Mo, 59.5%Co, 2%Si, 1%Mn, 1%Other) plates of the dimension of 15mm x 15mm x 0.15mm were divided in four groups.
In each group the plates were welded to obtain two samples of two plates welded in the median portion on the two sides.
The plates of the first group were welded by a Nd:Yag laser device normally used in dental office (Fidelis Plus III, Fotona, Ljubljana, Slovenia) without metal filler.
The plates of the second group were welded by the same device but with the apposition of a metal filler (CoCr- Schweissdraht, Dentaurum, Ispringen, Germany) (Co 65%, Cr 28%, Mo 5.5%).
The plates of the third group were welded by a Nd:YAG laser device normally used in dental technician laboratory (Rofin, Hamburg, Germany) without metal filler.
The plates of the fourth group were welded by the same device but with the apposition of a metal filler (CoCr- Schweissdraht, Dentaurum, Ispringen, Germany) (Co 65%, Cr 28%, Mo 5.5%).
The parameters used were the same as previously described.
In samples where filler was added, three passages were done: the first passage was realized without metal apposition to fix the position, the second one with filler and the third one without metal to regularize the welded fillet. In the other samples only the first and the third passes were done.
We used the described parameters, even if very different, because they are the ones currently used in dental laboratory by Rofin and in dental office by Fidelis.
Every plate was marked with an alphanumeric code and sent to the laboratory for the analysis with optical microscope, SEM and EDS: the analyst knew only the code but not the type of the samples in order to realize a blind study.

The samples were firstly englobed in epoxydic resin and then polished by abrasive papers and diamond pastes to 1 µm and observed by optical microscope, then chemical attack by HCl + H_2O_2 solution, and observations by SEM were realized.
SEM and EDS analysis was performed by Prof. Francesca Passaretti at CNR-IENI Laboratory in Lecco (ITALY) and mechanical tests were performed by Dr.Elena Villa in the same Laboratory.
In scanning electron microscopy (SEM), an electron beam is scanned across a sample's surface. When the electrons strike the sample, a variety of signals are generated and it is the detection of specific signals which produces an image or a sample's elemental composition. The three signals which provide the greatest amount of informations in SEM are the secondary electrons, backscattered electrons, and X-rays. (Goodhew et al, 2001)
Secondary electrons are emitted from the atoms occupying the top surface and produce a readily interpretable image of the surface. The contrast in the image is determined by the sample morphology. A high resolution image can be obtained because of the small diameter of the primary electron beam (Bozzola et al, 1999).
Backscattered electrons are primary beam electrons which are 'reflected' from atoms in the solid. The contrast in the image produced is determined by the atomic number of the elements in the sample. The image will therefore show the distribution of different chemical phases in the sample. As these electrons are emitted from a depth in the sample, the resolution in the image is not as good as for secondary electrons. (Julian, 2005)
Interaction of the primary beam with atoms in the sample causes shell transitions which result in the emission of an X-ray. The emitted X-ray has an energy characteristic of the parent element. Detection and measurement of the energy permit elemental analysis (Energy Dispersive X-ray Spectroscopy or EDS). EDS can provide rapid qualitative, with adequate standards, and quantitative analysis of elemental composition with a sampling depth of 1-2 microns. X-rays may also be used to form maps or line profiles, showing the elemental distribution in a sample surface. (Goldstein et al, 2003)
Twenty steel round orthodontic wires (Filo Tondo Duro Leone .030 C8080-30, Leone, Firenze, Italia and 14’’ Straight Wire, ortho Organizer Inc, San Marcos, Ca, USA) were also prepared as reported:
2 wires 0.75 mm not welded
2 wires 0.50 mm not welded
2 wires 0.75 mm welded by Rofin without metal filler
2 wires 0.50 mm welded by Rofin without metal filler
2 wires 0.75 mm welded by Rofin with metal filler
2 wires 0.50 mm welded by Rofin with metal filler
2 wires 0.75 mm welded by Fidelis without metal filler
2 wires 0.50 mm welded by Fidelis without metal filler
2 wires 0.75 mm welded by Fidelis with metal filler
2 wires 0.50 mm welded by Fidelis with metal filler
Metal filler, parameters and steps of the welding process were the same of these used for the plates.
The samples were analyzed by the Dynamic Mechanical Analysis (DMA) which can be simply described as the application of an oscillating force (stress) to a sample and the analysis of the material’s response to that force (Menard KP, 2008).

The appliance used was the Dynamic Mechanical Analyzer Q800 (TA Instruments, New Castle, Delaware, USA) which makes the tests in single cantilever configuration, under static or dynamic conditions and up to a maximum force of 18 N.
The limitation of this device is that it can analyse only samples of little dimensions and this was the reason why we used orthodontic wires.

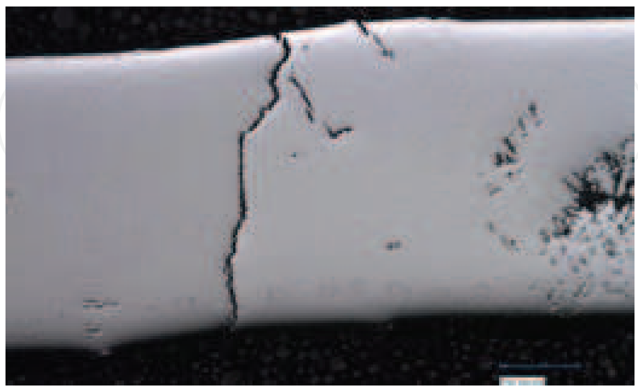

Fig. 7. Sample of laser welding by Fidelis without filler observed by optical microscope.

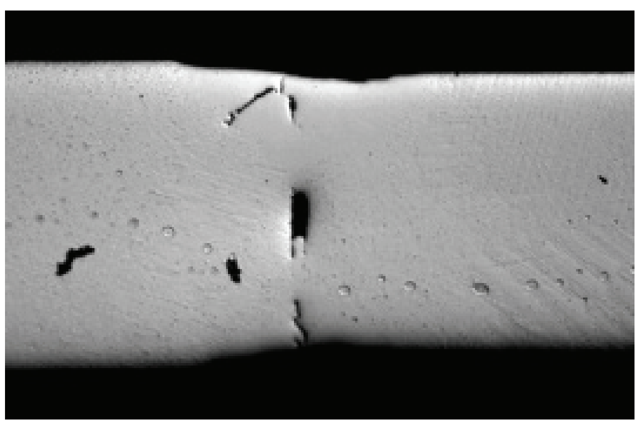

Fig. 8. Sample of laser welding by Rofin without filler observed by optical microscope.

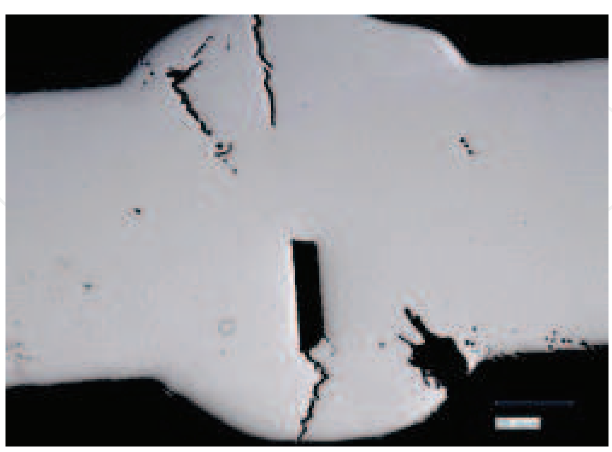

Fig. 9. Sample of laser welding by Fidelis with filler observed by optical microscope.

By optical microscope observation, the only significant difference between the groups regarded those welded without filler metal, in which it was seen a greater number of

fissuration in the plates welded by Fidelis plus III (Figg. 7 and 8) while in the groups with filler the differences were minimal (Figg. 9 and 10).
These aspects were confirmed by the observations of the samples after chemical attack by HCl and H_2O_2 and SEM observation (Figg. . 11-12-13 and 14).

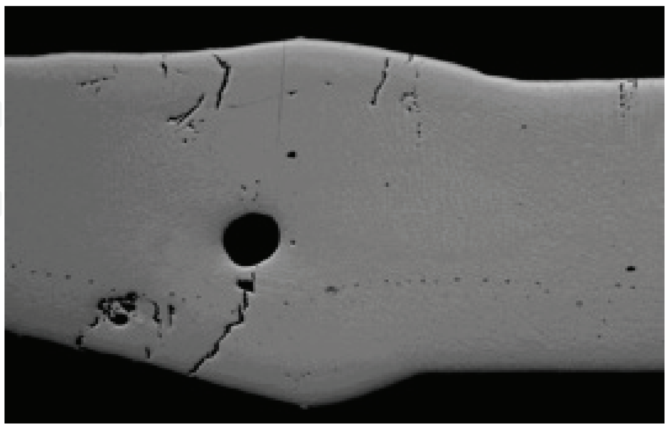

Fig. 10. Sample of laser welding by Rofin with filler observed by optical microscope.

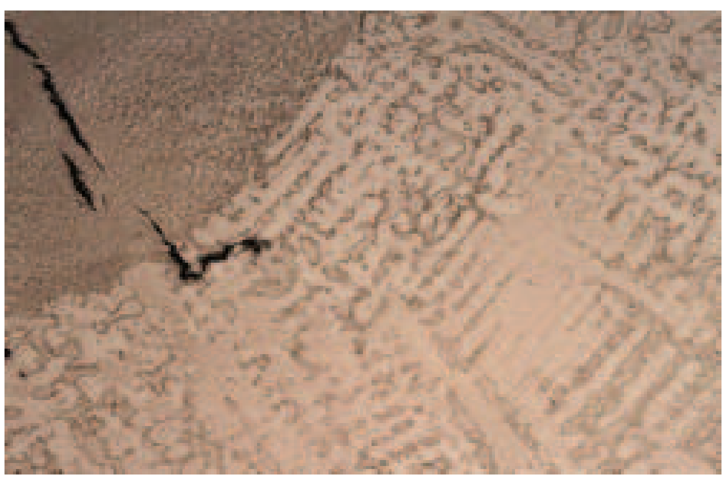

Fig. 11. Sample of laser welding by Fidelis without filler chemically attacked

Fig. 12. Sample of laser welding by Rofin without filler chemically attacked

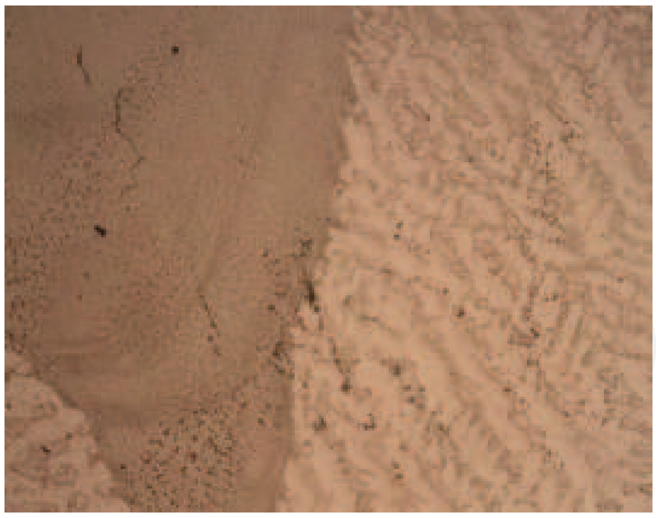

Fig. 13. Sample of laser welding by Fidelis with filler chemically attacked

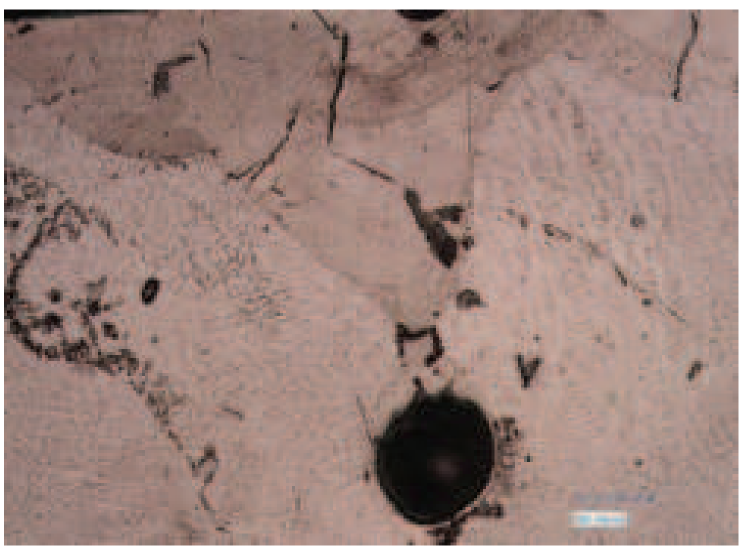

Fig. 14. Sample of laser welding by Rofin with filler chemically attacked

The EDS analysis in the welding zone showed an homogeneous composition of the CoCrMo alloy with no significant differences in the groups (Tabb. 1-2-3-4, results in %).

Spectrum	Co	Cr	Mo	W	C	Ga
1	57,67	23,33	5,57	7,57	2,86	3
2	58,64	22,18	5,71	8,28	2,82	2,38
3	58,98	22,41	5,57	7,77	2,8	2,47
4	58,64	22,32	5,97	7,91	3,11	2,06
5	58,43	23,42	4,7	7,43	2,98	3,05
6	60,26	22,45	4,29	7,06	3,01	2,91
7	57,26	23,03	5,32	7,58	3,62	3,19

Table 1. EDS analysis of plates welded by Fidelis without metal apposition

Spectrum	C	Cr	Co	Ga	Mo	W
1	3,86	22,93	57,71	2,68	5,2	7,61
2	4,57	22,34	57,31	2,32	5,6	7,85

Table 2. EDS analysis of plates welded by Rofin without metal apposition

Spectrum	Co	Cr	Mo	W	C	Ga
Spectrum 1	57,15	22,94	5,34	7,81	3,82	2,94
Spectrum 2	58,87	24,05	6,1	4,69	4,8	1,5

Table 3. EDS analysis of plates welded by Fidelis with metal apposition

Spectrum	C	Cr	Co	Ga	Mo	W
1	4,06	22,74	40,89	1,37	15,21	15,73
2	3,4	23,05	58,76	3,03	4,72	7,05
3	3,96	22,77	56,49	2,45	6,12	8,21
4	3,73	22,49	60,07	2,84	4,04	6,83

Table 4. EDS analysis of plates welded by Rofin with metal apposition

The mechanical tests done on orthodontic wires showed an elastic behaviour of the samples very similar (Tabb.5-6-7-8: green=not welded, red=Fidelis, Blue=Rofin)) with minimal differences between the samples.

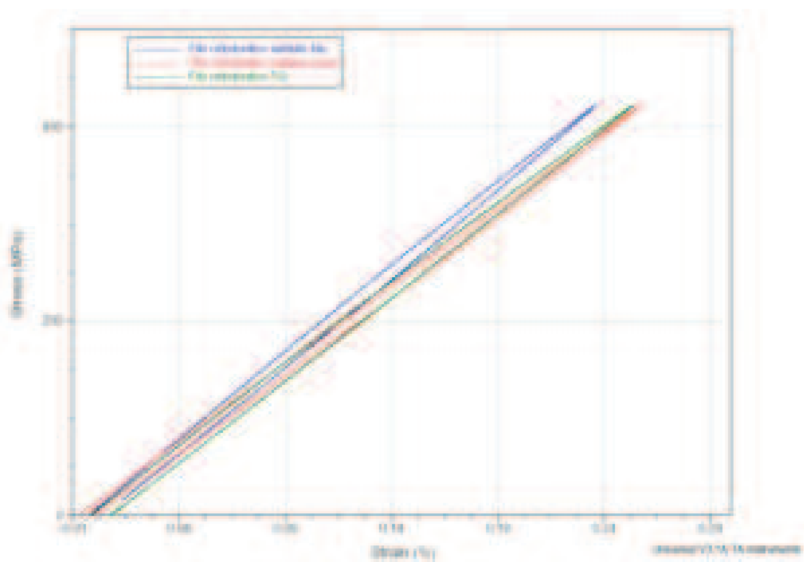

Table 5. Mechanical tests of wires up to 2 N

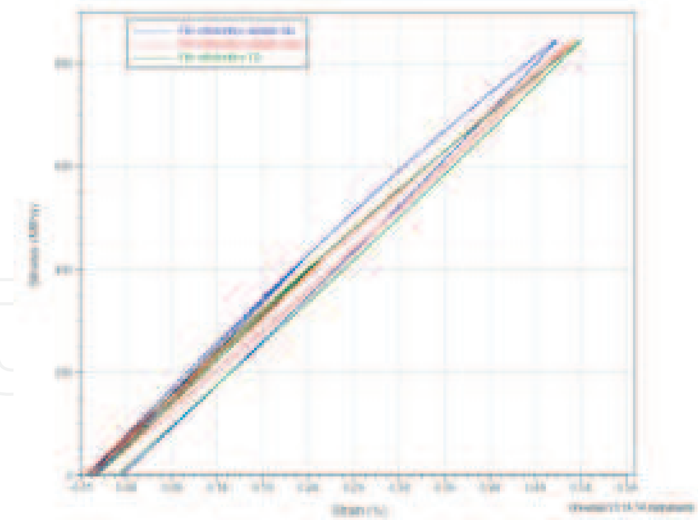

Table 6. Mechanical tests of wires up to 4 N

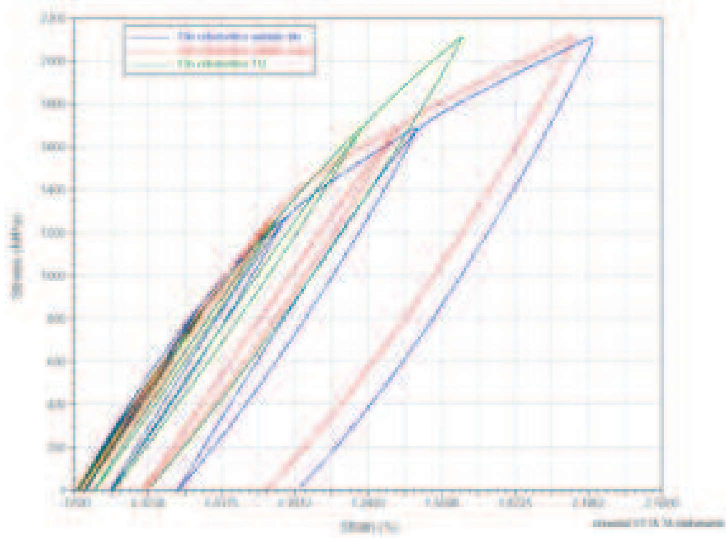

Table 7. Mechanical tests of wires up to 10 N

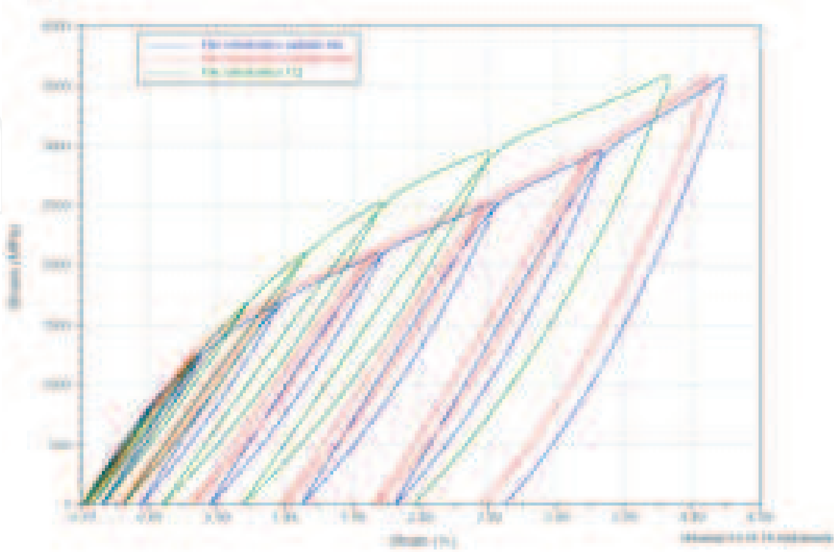

Table 8. Mechanical tests of wires up to 17 N

The residual deformation seen in the arches of 0.5 diameter was greater than in the arches 0.75 and in the arches welded with filler was greater than in those without and, in every case, no wire was broken even under the maximum strength.
The optical microscope observation of the wires after the mechanical tests didn't show significant differences between the samples. (Figg. 15 and 16)

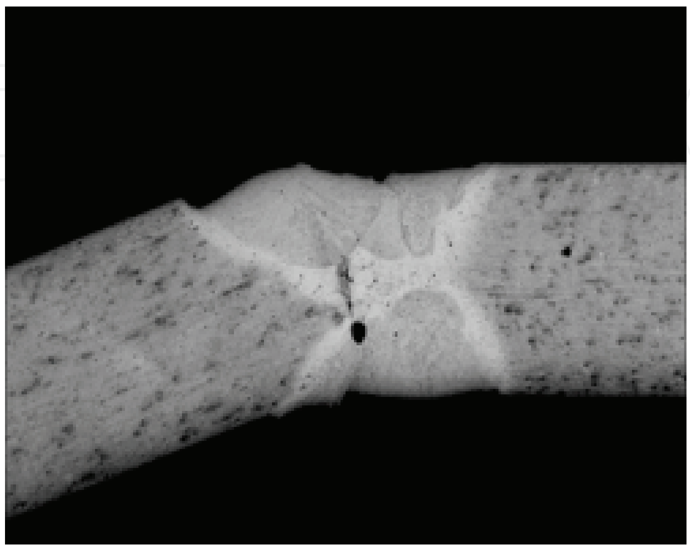

Fig. 15. Sample of laser welding by Fidelis

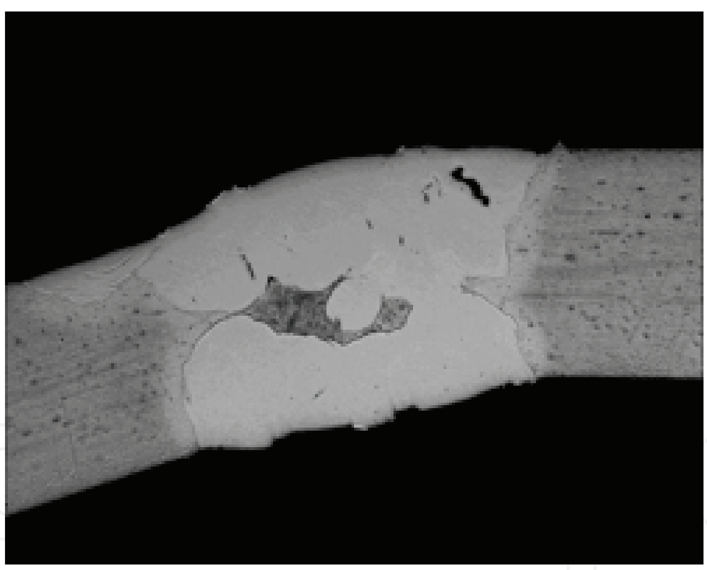

Fig. 16. Sample of laser welding by Rofin

Firstly it is necessary to do some general considerations about laser welding process to help the interpretation of these results
Laser technology is the most efficient method for applying thermal energy to small areas and, according to many Authors (Daves, 1992 and Ream, 1988), it is one of the best fusion welding techniques for dissimilar metals. This depends from the possibilty, by modern laser appliances to focus ligth beam to a fine focal point. This beam imparts energy into the metal causing to heat up locally to a temperature above the liquidus. The metal evaporates and a cavity is formed immediately under the heat source and a reservoir of molten metal is

produced around it. As the heat source moves forward, the hole is filled with the molten metal from the reservoir and this solidifies to form the weld bead. (Baba et al, 2004)
The presence of cracks on the fracture surfaces of the specimans were evident in several studies made on laser-welded Co-Cr-Co, while they were not reported on the fracture surface of the laser-welded titanium.(Watanabe et al, 2002)
This is due to the different values of thermal conductivity among metals: that of CoCrMo is higher than of the titanium.
After welding, the solidification of the molten CoCrMo alloy may occur more quickly, if compared with titanium: in fact the heat generated by the laser energy rapidly diffuses to the surrounding solid metal.
This rapid solidification causes a drastic constriction of the welded region at the same time.
Thus, a concentration of stress occurs at the laser-welded region , and so cracks are created. (Duhamel and Banas, 1983)
Also in the samples analysed in this study, fissurations and cracks were observed into the welded zone.
The greater differences between the plates welded by laboratory laser and these welded by dental office laser regarded the group without filler where these belonging to the second group had a greater number of cracks than these of the first group.
This difference was significantly reduced by the use of filler metal, and this is an important indication for our clinical practice where we decided to use always a filler metal.
The mechanical tests of this study hold an importance by the clinical point of view; in fact in all the tests with all the samples, the elastic module of the orthodontic wires was very high, and this means that our technique may be used intraorally as an aid to the orthodontic therapy.
We must emphasize that dental laboratory laser operates under an atmosphere of shielding gas, in this particular case argon, and this might be an important aspect regarding to the differences of the “without filler welded samples” two groups.
It’ll be interesting to observe if, comparing the same appliances utilised in this work, by using both of them under an atmosphere of shielding gas, the differences between the groups will be the same.
In order to make these tests and also to have the possibility to weld titanium we added to the appliance a gas cylinder connected to a pipe spreading to the laser impact beam.

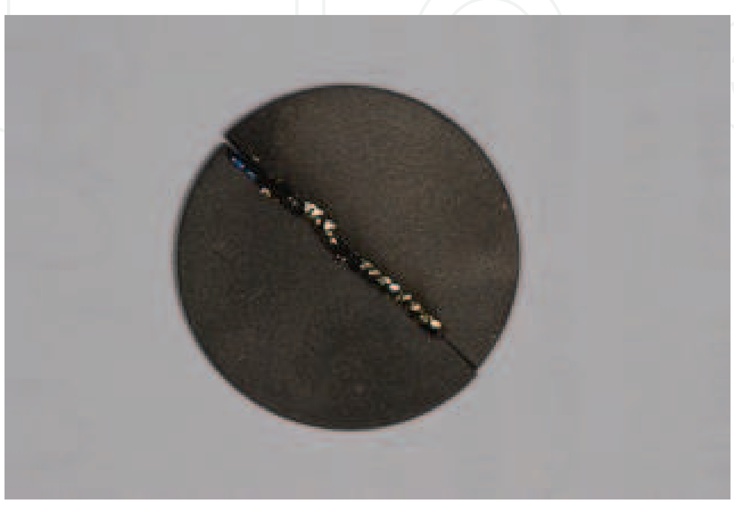

Fig. 17. Laser welded bid in titanium plate under argon atmosphere

In fact, shielding gas, is necessary to protect the weld area from atmospheric gases, such as oxygen, nitrogen, carbon dioxide, and water vapour that can reduce the quality of the weld or make the welding process more difficult to be used. (Watanabe & Topham, 2006)
Argon provides greater cleaning action than other gases, and, because it is heavier than air, it blankets the weld from contamination. For these reasons we decided to use argon, according to most of the Authors. (Yamagishi et al, 1993- Taylor et al, 1998)
So, we made some tests with Fidelis Plus III under an argon gas atmosphere on titanium plates, with and without apport metal, and we appreciated the absence of oxidation in the welded area. (Fig. 17)
In order to define thermal increase in the biological structures (sulcus, pulp chamber, bone and root) close to the thermal affected zone during the welding process, we made another in region and vitro study.
Two calf jaws freshly sacrificed were kept at room temperature and in six molars of each one a hole was made by a micromotor drill, in the distal- labial area.
Then, with the drill inserted into the tooth, its exact location into pulp chamber was checked by X-Rays (Fig. 18 and 19).

Fig. 18. Drill inserted into the tooth to evaluate the exact location of the drill in pulp chamber.

In each tooth, two further holes were made by a micromotor, one into the bone and one into the root.
Then, four thermocouples k-type were connected to every tooth and fixed with thermoplastic paste (Impression Compound Red Sticks, Kerr) into pulp chamber, sulcus, bone and root.
The thermocouples were then connected to a 4 channels Thermometer (LUTRON TM-946) PC-integrated in order to record and save data. (Fig. 20)

Fig. 19. Rx Check to evaluate the exact location of the drill in pulp chamber.

Fig. 20. 4-channel Thermometer (LUTRON TM-946) device.

Twenty-four metallic plates in ARGELOY NP SPECIAL (31.5% Cr, 5% Mo, 59.5 Cr, Co 2%, Si 1%, Mn 1%, others 1%), sized 5x35 mm and 0.5 mm thick, were curved to hemispherical shape (15 mm ray) and a couple of them was placed on each tooth previously prepared. (Fig. 21 and 22)

Fig. 21. Metallic plates in ARGELOY NP SPECIAL curved to hemispherical shape

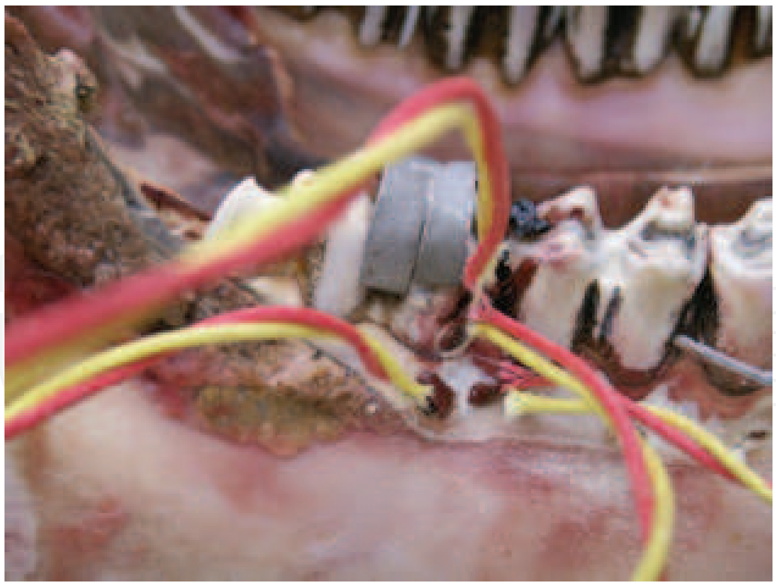
Fig. 22. The couple of metallic plates placed on every previously prepared tooth

Every plate couple was welded, by Nd:YAG Laser Fidelis Plus III, in three points (occlusal, vestibular and lingual) to fix the position and the thermal rise was recorded by the four thermocouples. (Fig.23)


Fig. 23. Metallic plates welded, by Nd:YAG Laser, in three points (occlusal, vestibular and lingual).

The parameters were:
OUTPUT POWER 9.85 W, FREQUENCY 1 Hz, PULSE DURATION 15 msec, SPOT DIAMETER 0.6 mm, WORKING DISTANCE 40 mm, ENERGY 9.85 J, FLUENCE 3480 J/cm2.
We have not taken into consideration the Rayleigh length which is the distance from the focus at which the cross-sectional area of the beam is doubled. That is very important in laser welding procedure and we believe this might be the spotlight of a next in vitro study

even if we think that it's very difficult to keep a constant focal distance during intraoral welding procedure.
The recorded values were integrated by PC software (LUTRON SW-U801-WIN) in order to have an image of the highest, lowest and mean values .
The higher thermal elevation was pointed out by thermocouples inserted into the pulp chamber while the lowest regarded the bone.
The standard deviation (SD) was under 0.5.
The Mean values of temperature increase were as follows:
Pulp chamber: Mean value: 0.714 ± 0.45 °C (Max: 1.5 °C; Min. 0.1 °C).
Bone: Mean value: 0.100 ± 0.1 °C (Max: 0.3 °C; Min. 0.0 °C).
Sulcus: Mean value: 0.442 ± 0.43 °C (Max: 0.7 °C; Min. 0.1 °C).
Root: Mean value: 0.231 ± 0.24 °C (Max: 0.3 °C; Min. 0.0 °C).
We have made the first examination of this work with thermal camera by recording the metal welding processes: the limit of this device lies in the possibility of getting only a jaws surface evaluation. This is the reason for using the four thermocouples system which, even if more difficult and longer to perform, allows checking internal temperature of the structures.
Higher thermal rise was recorded in the pulp chamber; however, for all the twelve samples tested, the maximum temperature rise was lower than 5.5°C, which is considered as critical value for pulp vitality (Oelgiesser et al, 2003- Martins et al, 2006- Sulieman et al, 2006) and, in any case, it was lower than in the other studies regarding brazing process through an electric arc between two electrodes . (Shibuya et al, 2004 and Haney et al, 1996)
In the sulcus, too, the temperature increase was very low and yet lower than 1 degree. In bone and roots, the temperature increase was practically absent and this is particularly interesting because it allows expecting an in vivo clinical use in order to connect titanium bars to fixtures without damaging bone and compromising the Osseo-integration of implants.
Probably, the low number of shots (4 to 5) sufficient to fix the two metallic parts and the low Fluence transferred to the biological structures (Fluence= J/cm2; J=W/s) explain these interesting results for low temperature rise and so the temperature increase values in tissues keep below dangerous limit for integrity.
Laser welding process in metallic structures applied to mandibular molars causes a very low thermal rise in surrounding areas. This technique can be considered as biologically compatible and without the risk of necrosis.

Clinical Cases

1) Extraorals
Case 1
Patient TC, male 8 years old, in treatment in our office with a removable orthodontics appliance of Schwartz, came to us for the periodic check of the appliance and we saw that one of the Adam's hooks was broken (Figure 24).
We welded it without filler metal (Figure 25) and the plastic shield, even if very close to the welded zone, did not result damaged or modified.(Figure 26)
We could re-apply the repaired appliance to the patient only after some minutes.(Figure 27)


Fig. 24. Appliance with Adam's hook broken.

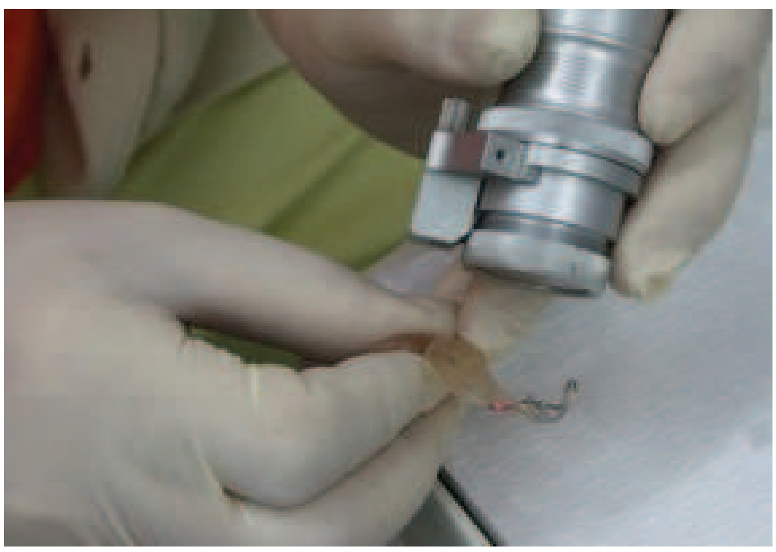
Fig. 25. Laser welding process without filler metal


Fig. 26. Hook repaired without damaging acrylic portion close

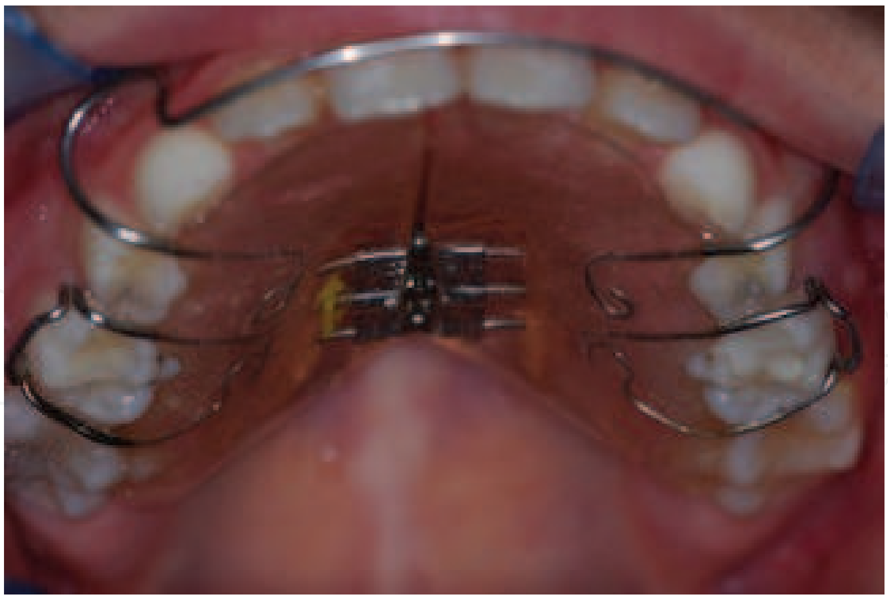

Fig. 27. Appliance replaced into the mouth

Case 2
Patient RK, 49 years old female came to our office with her removable prosthesis broken in the metallic portion. (Figure 28) Due of the impossibility to determine the exact position of the two fragments, we took an impression with the prosthesis inserted into the mouth and we prepared a stone model. (Figure 29)

Fig. 28. Broken removable appliance: Impression

Fig. 29. Laser Welding

Then, we welded the two parts by Fidelis Plus III directly in our office utilizing filler metal without damaging or destroying the acrylic parts. (Figures 30)
After polishing the prosthesis, we applied it into the patient mouth just after half an hour. (Figure 31)

Fig. 30. Prosthesis re-applied into the mouth

Case 3
Patient ML, male, 43 years old, came urgently to our office with acute hypersensitivity, particularly from cold drinks, localized to the left mandibular area. The clinical examination showed that the lower left bridge was damaged in the occlusal surface of the crown of 37 (fig. 31). The problem was that the patient had to go on a three-weeks business trip the day after. So, we decided to remove the bridge, control the vitality of the tooth 37 and being sure it was free of any decay we repaired the crown directly in our office with the laser(fig. 32). Then, the crown surface was polished and the bridge re-cemented onto the teeth (fig. 33).

Fig. 31. The damaged bridge

Fig. 32. Bridge repaired by laser welding in dental office

Fig. 33. The repaired bridge replaced into the mouth

2) Intraorals

Case 1:
Patient 59 years old male with fixed prosthetics placed in to the upper arch, with two crowns and five bone implants. (Fig. 34)
After the crowns preparation and the taking of the impressions, dental technician constructed the metallic structure of the bridge in two sections to assure fit.
In order to protect the soft tissues from the ejection of warm metal splinters, we made a sort of mask by silicon normally used to take prosthetic impressions with a little hole corresponding to the contact of the two portions of prosthesis. (Fig. 35)
Then we started to weld the bridge with the apposition of filler metal on the two parts. Filler material used was Bego WiroWeld 2 mm diameter, (Co 65%, Cr 28%, Mo 3.5%, others 3.5%)
After removing the bridge from the mouth, it was sent to the laboratory to complete its realization. (Fig.36)
During and after welding process patient said he did not feel any discomforts.
After three weeks we could seal the bridge and finish the rehabilitation of the patient. (Fig. 37)

Fig. 34. Patient with preparation of two crowns and five bone implants

Fig. 35. Intraoral laser welding of the two portions

Fig. 36. Bridge ready to be sent to the dental lab

Fig. 37. Completed prosthesis placed into the mouth

Case 2:
Patient SV fourteen years old male come to the office with the lingual wire of the appliance broken. It was an orthodontic appliance called Delaire which consists of two wires, one vestibular and one lingual, connected to two braces on first upper molars. (Fig. 38)
We made the screen in silicon in order to protect soft tissues and we welded the appliance without filler metal.
Laser device, fiber, handpiece and parameters were the same as before, and the entire operation had a duration of four minutes, the welding time was 75 sec. (Fig. 39)
So, after few minutes and without sending the appliance to the dental laboratory and without discomfort for patient, we could repair it. (Fig. 40)
The follow-up, made monthly for six months, demonstrated that the appliance was active and strength-proof.


Fig. 38. Broken orthodontics appliance


Fig. 39. Intraoral laser welding


Fig. 40. Appliance repaired

Case 3:
Patient CV 45 male old come to our office to made a prosthetic rehabilitation of lower arch. In upper arch he had a gold-resin fixed prosthetics broken in the middle, between the two central incisors. (Fig. 41)
So, we decided to use our new technique to repair the bridge intraorally. We removed a little portion of resin by the two incisors with a bur and we welded by Fidelis III with filler metal. In this case the protection of soft tissues was done by a plastic cylinder. (Fig. 42) After welding, we put a layer of composite resin to complete, by an aesthetically point of view, the restoration. (Fig. 43)
During welding process, which had a duration of seven minutes, the patient did not feel any discomfort.
Subsequent checks, made after one, two and six months did not evidence any kind of problems.

Fig. 41. Fixed prosthesis broken between the central incisors

Fig. 42. Intraoral laser welding


Fig. 43. Prosthesis repaired

Discussion and Conclusion

We have described, in every aspect, the use of Nd:YAG laser to weld appliances, extra- and intra-orally, directly in dental office by dentist himself.

Tests we made seem to demonstrate that Fidelis plus III is able to make a real welding process on different kinds of metal, with and without apport metal, with and without shielding gas and with good strength of the joints, even after months.

This gives the possibility both to repair broken prosthesis without their deplacement from the oral cavity, both the fixation of the position during the process of fabrication, avoiding the necessity of the use of silicon impression and/or resin and so reducing the possibility of inaccuracies due to the transfer of the impression to the laboratory.

During this study we had to solve different problems related to the fact that the appliance used was not projected to weld. So, our aim was to find technical solutions about parameters and device modifications in order to reach a good result, by a point of view of the quality of process welding, and also by the patient safety aspects.

Several problems remain unsolved but, with the help of manufacturer, this may be the aim of future studies.

The first unsolved problem is concerning the possibility to have special chemical glasses, connected with laser, with the possibility to obscure for a very short time during the shot, such in industrial field and in laboratory welding laser.

In fact, the shining of the interaction between the beam and metal is very troublesome for the operator.

The second one is linked to the opportunity to have a contra-angle handpiece in order to weld also in posterior areas of the mouth.

But the most interesting result is that patients, during intraoral welding and in the following days, has not shown trouble, pain and problem to the dental and periodontium structures of the support elements and the vitality tests performed are regular.

This first *in vivo* tests proved that using the laser technique to get the intraoral welding of metal prostheses can be possible with neither particular problems nor risks for the biological structures close to the welding zone.

Further tests will surely be necessary to confirm our work; however, we may say that it opens a new interesting perspective in modern dentistry.

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This book is entitled to laser welding processes. The objective is to introduce relatively established methodologies and techniques which have been studied, developed and applied either in industries or researches. State-of-the art developments aimed at improving or next generation technologies will be presented covering topics such as monitoring, modelling, control, and industrial application. This book is to provide effective solutions to various applications for field engineers and researchers who are interested in laser material processing.